Deep Extragalactic Surveys

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Introduction

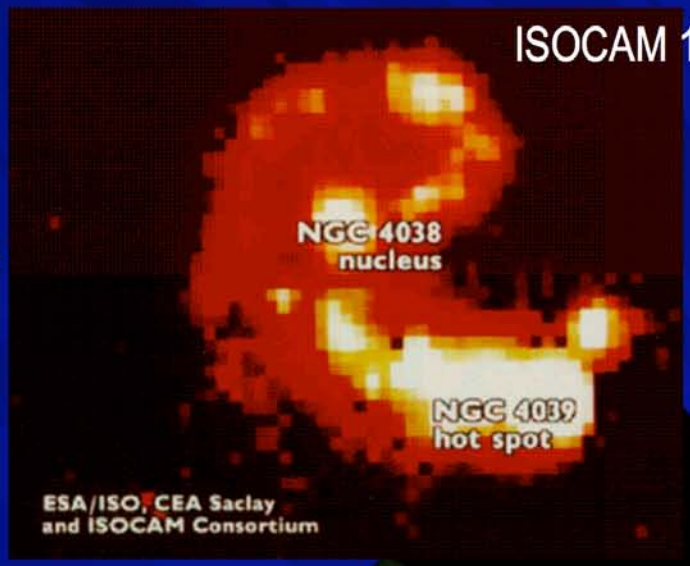
- Galaxy evolution is now studied against a fixed set of initial conditions
- The details of gas processing, stellar/AGN feedback and interactions remain incomplete
- The true shape and evolution of the luminosity function of galaxies is unresolved
- Where does CCAT fit in?

The context

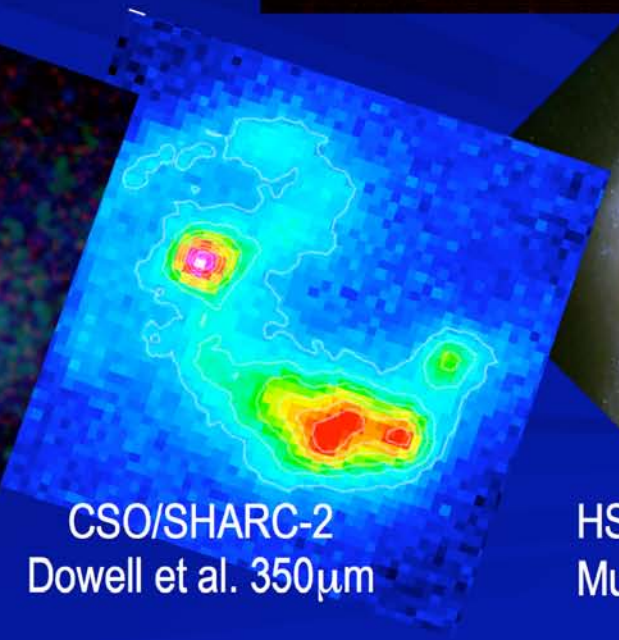
- Optical spectra reveal details of galaxies to reionization, and hints beyond
  - 8-10 m class telescopes … TMT/ELT
- Quantifying obscuration and avoiding deceptive 'frosting' are always necessary
  - IRAS / ISO / Spitzer … Herschel / ALMA
  - Planck / WISE all-sky surveys
- The mechanisms driving evolution require knowledge of environment and duration of activity
  - 1-10 Mpc structures (2'-20' in extent)
  - Structures separated by ~100Mpc (~3 deg)
  - useful sample over full LF requires Gpc^3 volumes

A hint of astrophysical detail

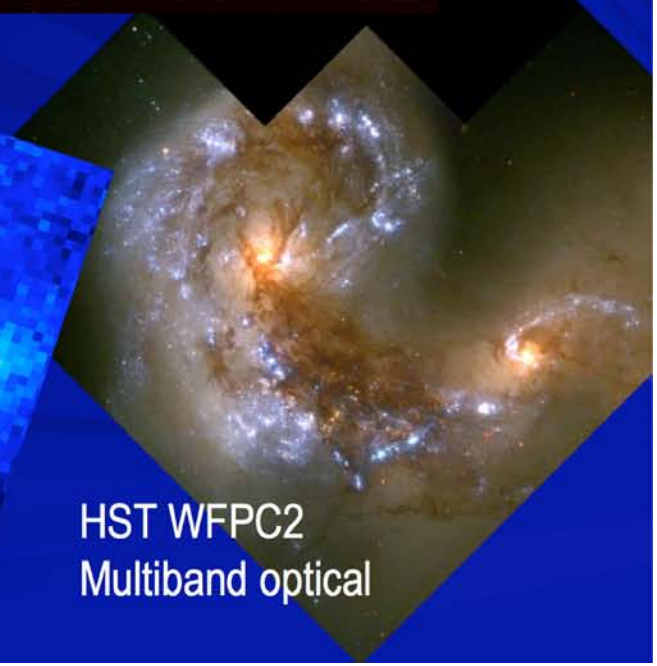
An excellent example when nuclear, GMC, stellar and ISM emission are revealed at different places in the UV through submm
About 90% of energy escapes at far-IR wavelengths



Spitzer IRAC
mid-IR



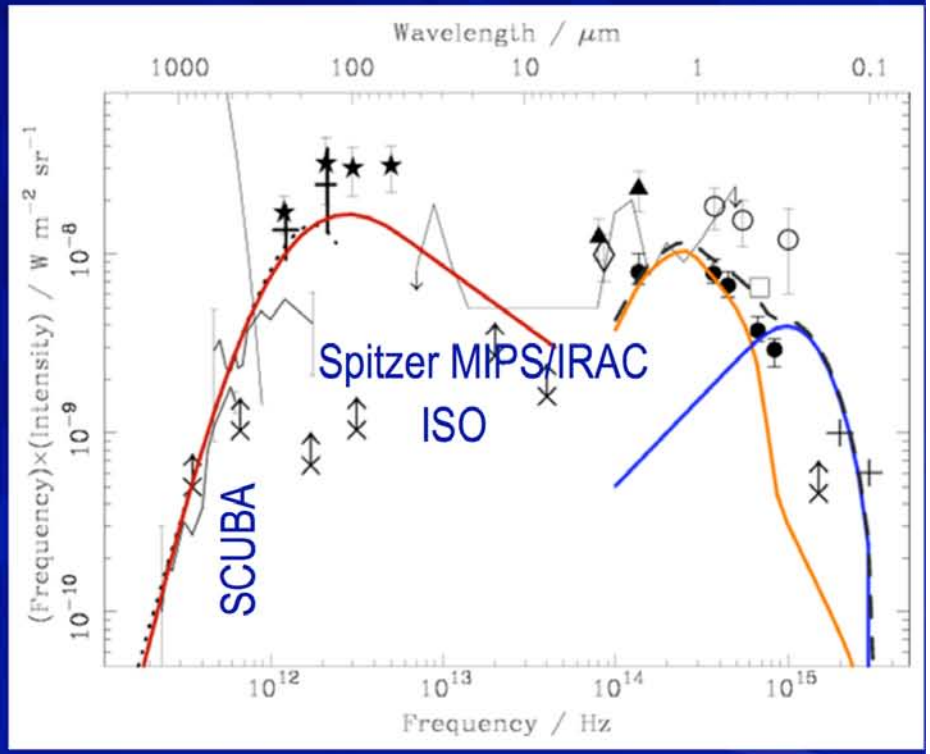
CSO/SHARC-2
Dowell et al. 350μm



HST WFPC2
Multiband optical

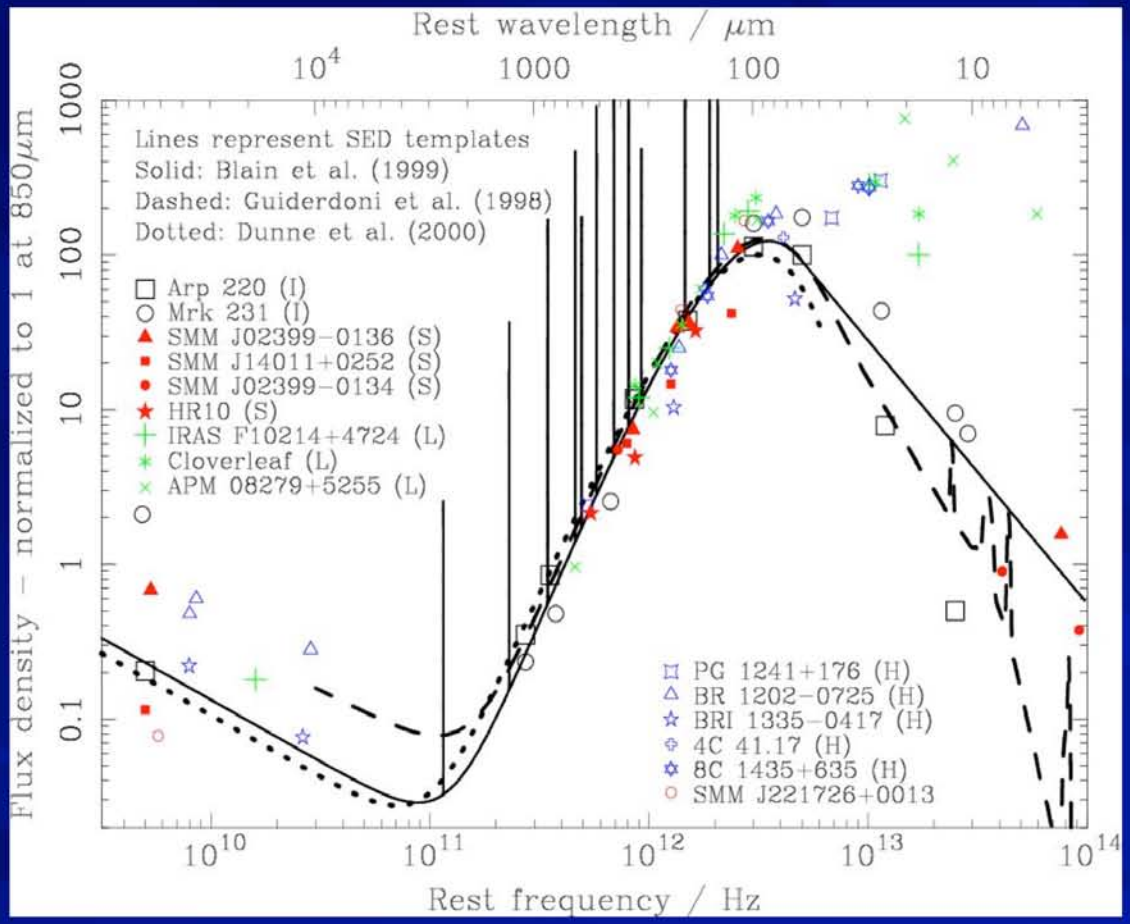
Obscured galaxies: background

Many sources of data
Total far-IR and optical background intensity are comparable
Most of the submm (0.85mm) background detected by 14" SCUBA resolution
ISO and more precise
Spitzer images detect ~20-30% in mid-IR
Note: backgrounds yield weaker constraints on evolution than N(>S) counts



Models: BJSLKI 99

Observed far-IR/submm SEDs



Normalized where sizeable sample of `submm galaxies' are known. Redshifts z~2-3 for 73 from Chapman et al.

- Mix of different sources traces out **some** of the range of SEDs properties
  - Milky Way & APM08279 are most extreme shown
- Non-thermal radio
  - Radio-far-IR link
- Thermal dust
  - Dominates luminosity
  - Hotter & broader in AGN?
- PAH C=C line features

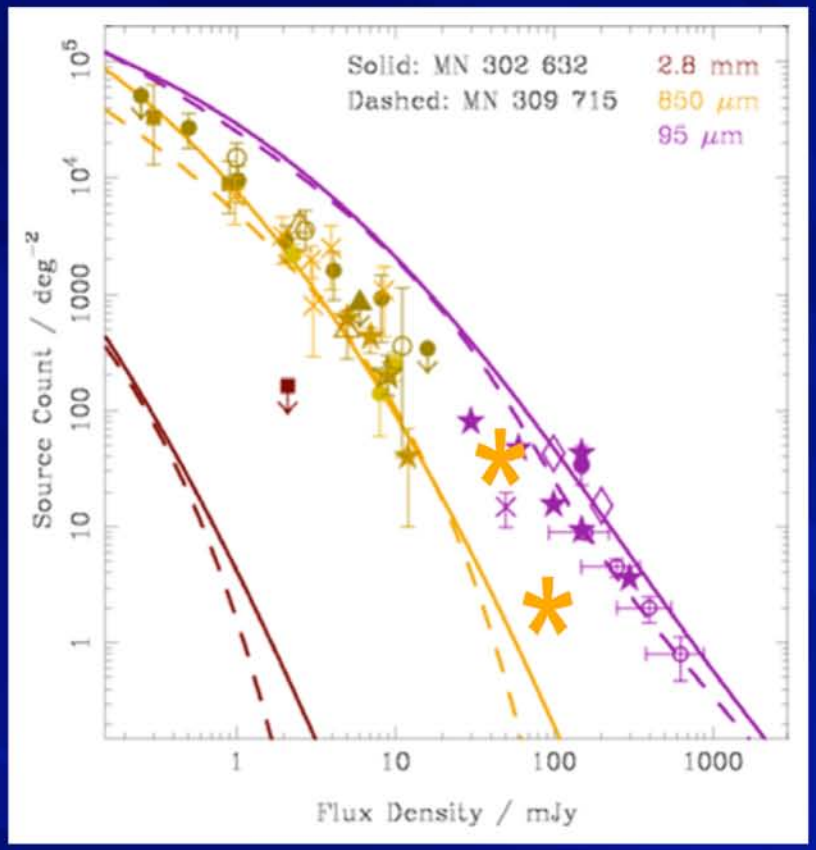
Requirements for future

- Resolution: ALMA
- Quantifying luminosity: multi-band data, always including submm & far-IR
  - Radio can be proxy for mid/far-IR
  - Distance also required: CO or atomic spectra
  - Follow-up is arduous now
  - Future surveys need to provide better positions and more spectral information
- Finding true range of candidates' properties
  - Volume surveyed includes representative number of all environments, implies 100's of square degrees

Existing surveys

- SCUBA, MAMBO, BOLOCAM, AzTEC, SHARC2
  - About 400 sources in total
  - About 120 with redshift information
  - About 30 with dynamical information
- Follow-up involves radio, mm interferometer continuum, optical/near-IR spectra, rest near-IR continuum, X-ray spectroscopy
  - Full range of available resources
  - Time demands now imply using mostly archived data

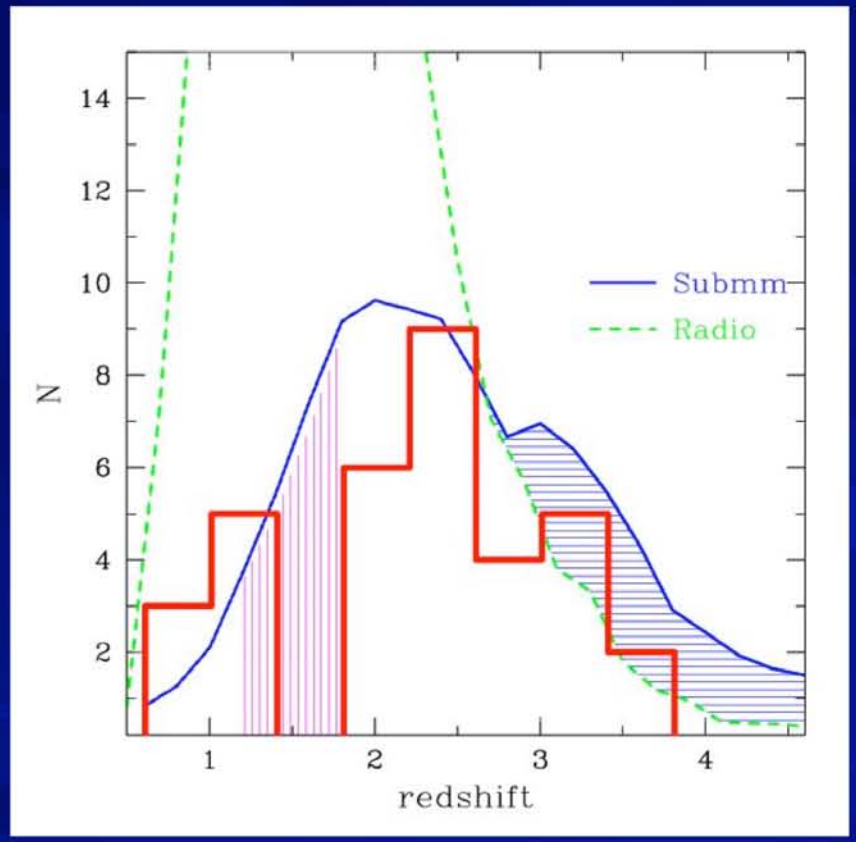
Population of dusty galaxies



Orange stars – Barnard et al (2004) 850-μm upper limits

- Most data is at 850 μm
  - Bright limit from Barnard et al (astro-ph/0405156)
  - Very few are Galactic contaminating clouds
- First 2.8mm limit from BIMA
- Bright 95 (&175) μm counts from ISO being dramatically improved at 70 & 160 μm by Spitzer (started August 04 ApJS)
- Also data at 1.2mm (IRAM's MAMBO); 1.1mm (CSO's BOLOCAM) and 350/450μm (SCUBA & SHARC-2)

Redshift distribution N(z) for radio-pinpointed SMGs

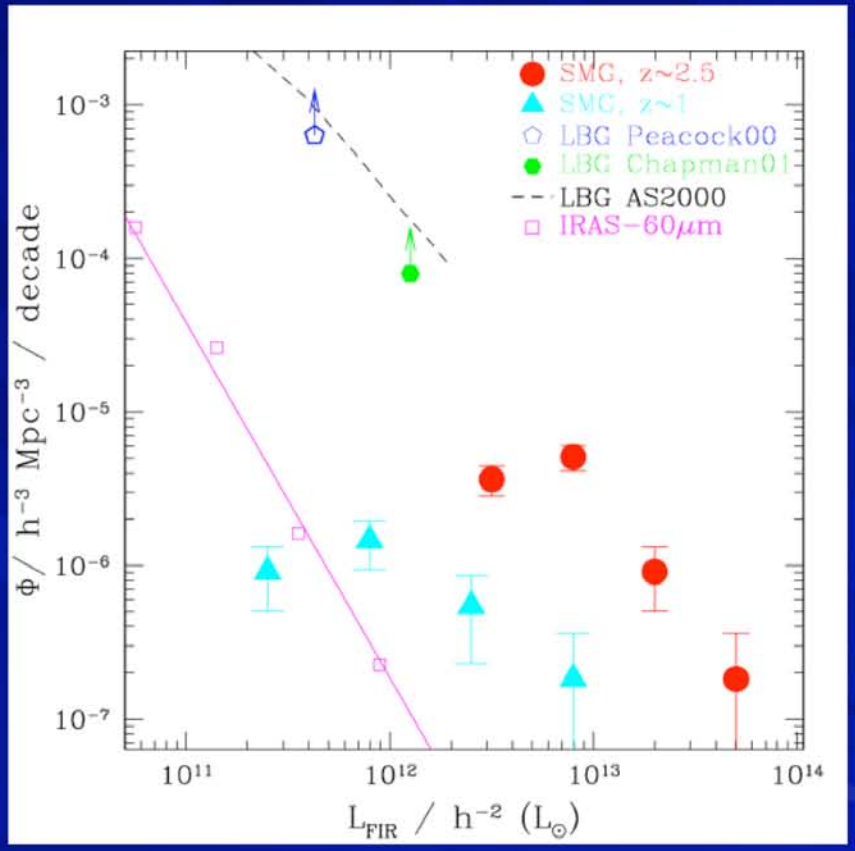


Chapman et al. (2003; 2005)

- Red histogram: Chapman et al ApJ 2005
  - 73 redshifts
  - Median z=2.4 and spread in redshift z~0.65 is good description
- Lines: expected submm & radio N(z)'s from Chapman's model
  - Magenta shade at z~1.5 is 'spectroscopic desert': rest-UV & rest-optical lines both hard to observe
  - Blue shading at highest z is incompleteness due to radio non-detection. Likely modest, but uncertain
- Difficulty of finding positions will vanish with ALMA

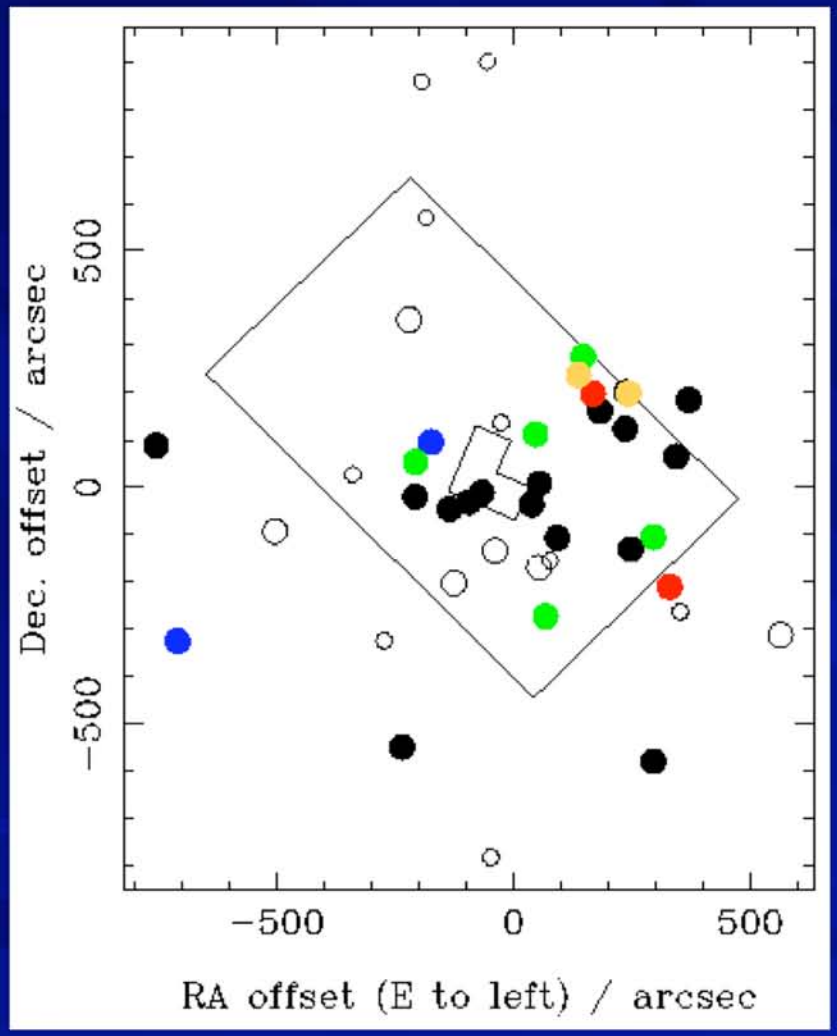
Luminosity function

- Based on known redshifts and fraction of population with redshifts (~50%) can see dramatic evolution from z=0 to 1 to 2.5
- Plausible connection to the luminosity function of optically-selected high-z galaxies
  - Lower limits as only a fraction of far-IR luminous objects are detected in UV surveys
- Interesting to obtain Spitzer LF results at z~1-2 for comparison
- Key goal is overall high-z LF
  - Current limit is few 10^{12} L_o
  - Most high-z samples 10x fainter



Chapman et al. (2005); astro-ph/0412573

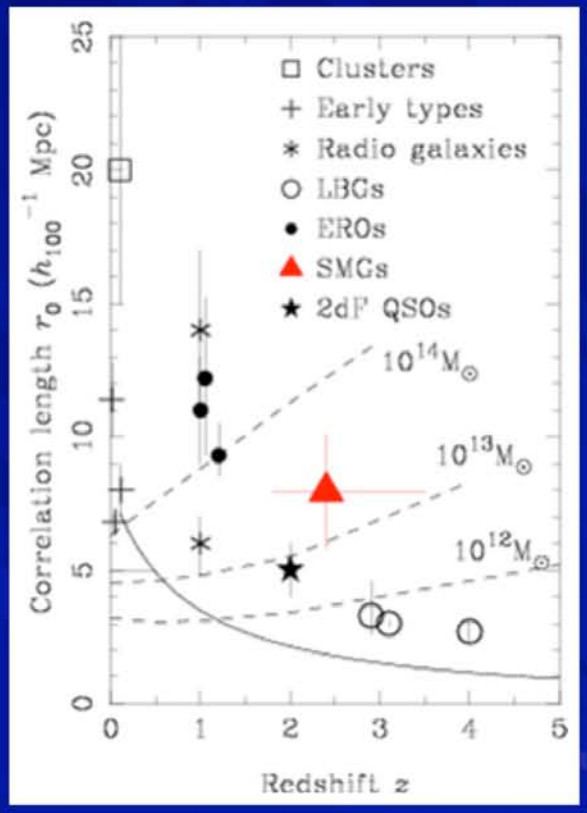
SMGs trace 3D large-scale structure peaks?



- Largest number of SMGs are in and around the HDF field
  - HDF & GOODS frames show where morphology information is available
- Circles: all known radio-submm galaxies
  - Small empty: no z attempt
  - Large empty: no z found
  - Black filled: z found
  - Colored filled: ‘associations’ - all z’s within 1200 km/s
- Green points (z=1.99) match optical galaxy z spike (Steidel et al)
- Only spectroscopic redshifts can reveal this structure
- Many more ‘clusters’ or associations expected than expected from our knowledge of SMG N(z)
- Narrow-band searches under way

Comparison with other populations

- Other more numerous high-z populations have less powerful clustering
- Are SMG redshift associations linked to overdensities of more numerous galaxy classes at the same redshift?
  - At z~2.5 spectroscopy essential to test
  - Links with 'BX' optically selected galaxies at z~2 in HDF
  - Narrow-band imaging with LRIS in March to search for associated optical galaxies
- Do they reside in such massive halos?
  - Not every 10' field can contain such an object
  - What is the nature of the biasing process?
  - Near-IR spectra hint at central 4-kpc dynamical masses of few $10^{11}M_o$
  - Stellar population fitting implies few $10^{10}M_o$, but uncertainties from complex morphology
  - OSIRIS resolved spectra will be exciting

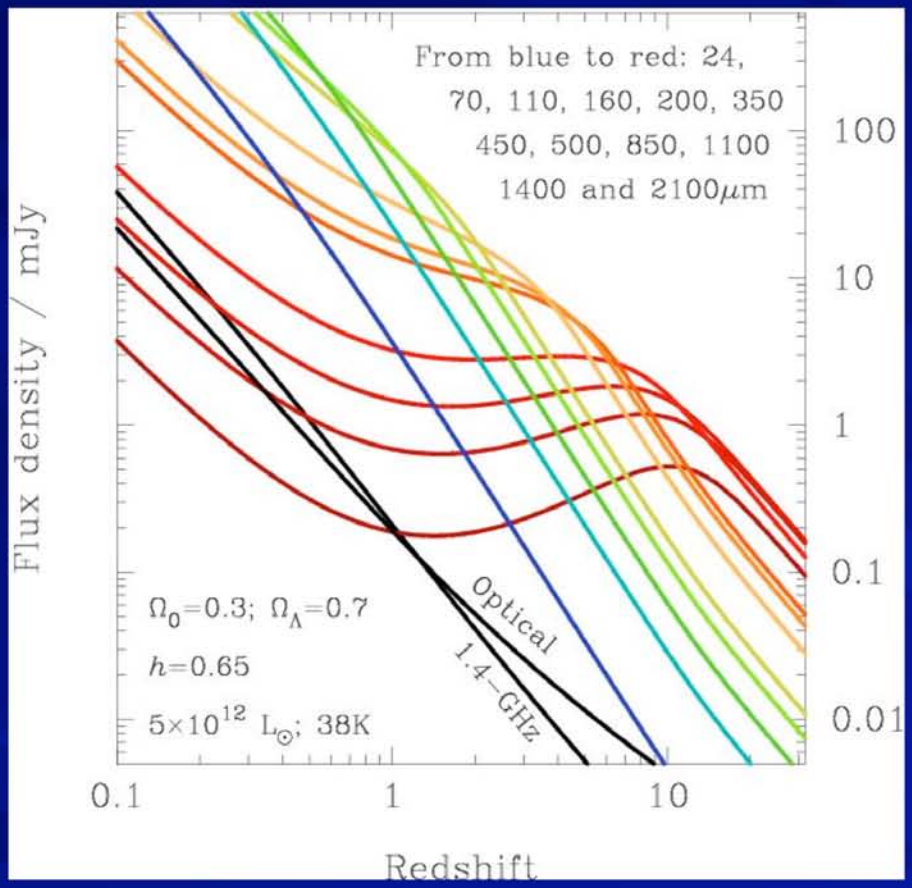


After Overzier et al. (2003)

Volume to cover

- Current surveys target ~1 deg^2 to z~4
  - 7 Gpc deep
  - 25 Mpc wide (at z>0.5)
- Large-scale structure extends ~200 Mpc:
  - Want 10x10 deg fields
  - Matching Spitzer legacy
- Several 1000 galaxies per square degree, but many fewer bright 'Rosetta stones'
- Correlation length is 5-10 Mpc:
  - would like more cubic volumes not skewers
  - Implies field sizes out to 30-40 deg (1 Gpc) would be worthwhile
- These far exceed existing survey fields
  - LSST / eVLA to come
- Galactic caps from Planck & WISE will be uniquely attractive targets
  - Galaxy science directly
  - CMB foreground in parallel

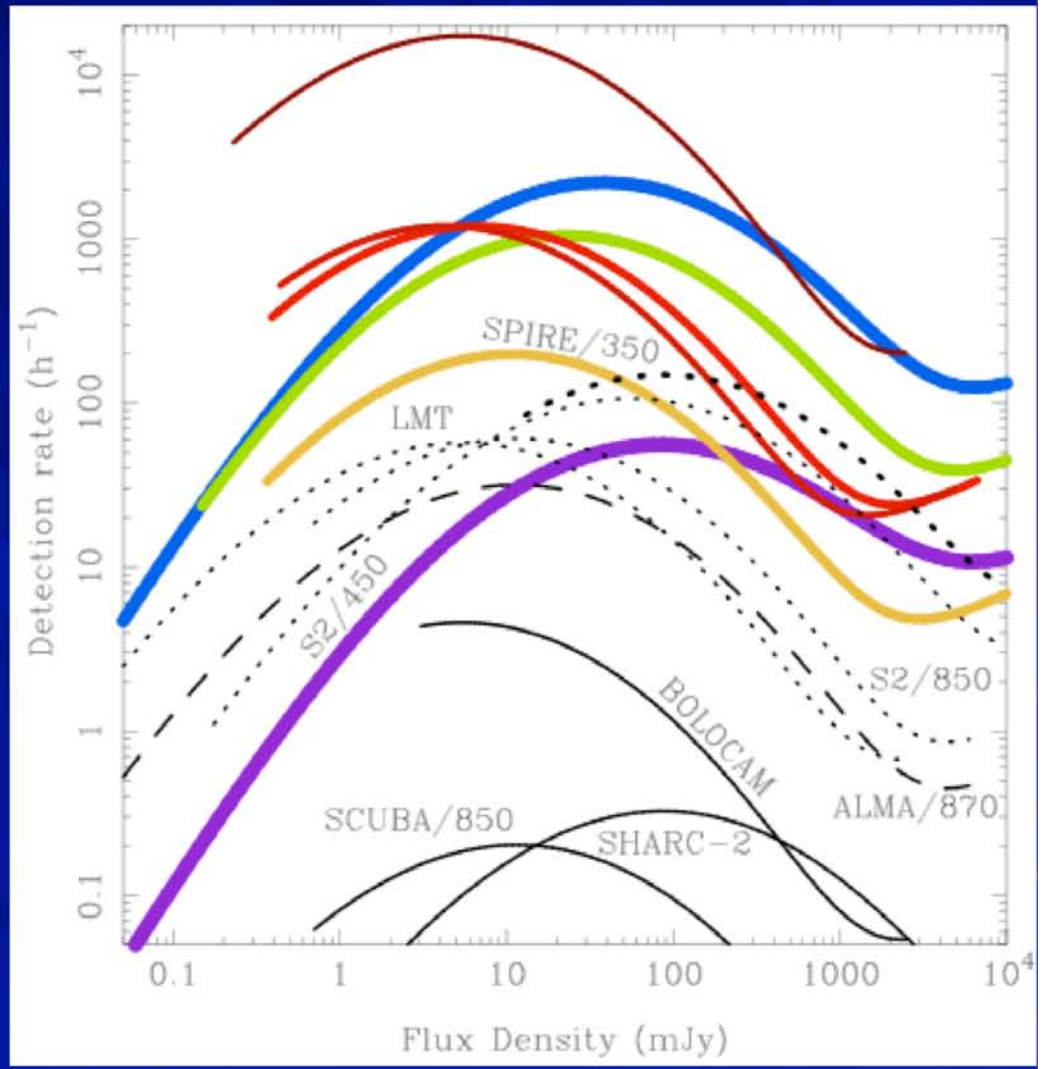
Mm/submm wave access to high-z



- Redshift the steep submm SED to counteract inverse square law dimming
  - High-z galaxies as visible as those at z~0.5
  - Low-z (and low-L) galaxies do not dominate submm images
  - Can be confident all sources are distant
- Ultimate limit to redshift extent at z~10 is set by CMB heating
- 2mJy at 1mm ~5×10^{12} L_o
  - Note ~few mJy matches current depth of submillimeter surveys
- A deeper survey finds more galaxies at all luminosities/redshifts

CCAT: Speed vs other instruments

- ALMA, SCUBA-2, 50-m LMT, Herschel
- Assume CCAT cameras
  - 1100, 870, 740, 620, 450, 350, 200 μm SWCAM 32000 pixels
  - LWCAM 16000 pixels
- Fastest depth ~few mJy at 1100μm
  - FOV 25 arcmin^2
  - 1mJy 5σ in 30s
  - 1/2-sky survey in 2.5 yr
  - 10^8 galaxies
- Confusion limited (350micron)
  - 0.05mJy 1σ in 600s
  - 2 deg^2 in 40hr
  - 10^6 galaxies over few yr
- Huge galaxy surveys
- CMB foreground maps
- Note other devices
  - ALMA is hindered by small FOV
  - SPIRE is confusion limited
  - LMT could reach high speeds at 1100μm with LWCAM-type detector, but not at SWCAM wavelengths



Uses of huge samples

- Highlight likely high-density areas at z~2
- Find rare pre-reionization (red) sources, that drop out in optical/IR bands
- Match the existing spectral database from SDSS, and photometric redshift surveys in future
- Define luminosity function to few % accuracy over decades of brightness
- Make angular correlation measurements in interim before redshifts are sifted
- Match low-background fields from WISE, Herschel, Planck and future CMB imagers
- Definitive foreground population for CMB

Summary

- CCAT's beam is less confused
  - Goes deeper to match other populations
  - Source density better matched to follow-up
- CCAT goes wider to find
  - Millions of galaxies
  - Their threading through large-scale structure
  - In thousands of clusters (probably - see SCUBA-2)
  - Entirely complementary to ALMA
- Excellent weather implies more uniform 350/450 micron coverage
  - Combines with resolution
  - Pre-selection via color for ALMA